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Shaded Computer Graphic Techniques
for Visualizing and Interpreting
Analytic Fluid Flow Models

NASA Grant NSG 3207

FINAL REPORT

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**Shaded Computer Graphic Techniques
for Visualizing and Interpreting
Analytic Fluid Flow Models**

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July 1978 - June 1981

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**Application of 'SCAN' technique
to
Representation of Fluid Flow**

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Background

Mathematical models which predict the behavior of fluid flow in different experiments are simulated using digital computers. The simulations predict values of parameters of the fluid flow (pressure, temperature and velocity vector) at many points in the fluid. Visualization of the spatial variation in the value of these parameters is important to comprehend and check the data generated, to identify the regions of interest in the flow, and for effectively communicating information about the flow to others.

The study, whose results are presented here, is part of a continuing effort in applying state of the art imaging techniques developed in the field of three dimensional shaded computer graphics to visualization of fluid flow (Some previous research along these lines can also be found reported in the Final Report of NASA Grant NSG 3115).

Use of an imaging technique known as 'SCAN'[1] for visualizing fluid flow, is studied and the results are presented here.

SCAN Animation

"In scan animation, each frame is a time lapse photograph of a changing environment[2]. The environment usually consists of some type of flat art (two dimensional drawing, etc.) positioned on an animation stand. Changes in this environment usually consist of moving the art work and/or moving the camera position. When the artwork or camera position are moved during exposure, this has the effect of leaving a trail or a smear along the motion trajectory"[1].

"Say we want a scene in which an object appears at point A, then moves to point B, leaving a trail from point A to point B and finally the trail catches up to the object at point B. This is accomplished by positioning the object at point A and exposing the first frame of scene. For the next frame, the object is again positioned at point A and then, with the shutter open, moved an increment towards point B. For the next frame the object is again positioned at point A and with the shutter open moved two increments toward point B. In subsequent frames, the object starts at point A and moves further toward point B until the frame is reached in which the object moves all the way from A to B. In each of these frames the object has the same

starting point, A, but a different ending position. Now, to make the trail catch up to the object at point B, the movement on each frame will have the same ending position, B, but a different position between A and B. "[1]

Thus, SCAN image can be produced by placing a pattern at a sequence of positions and superimposing the images to produce an integrated image. The successive positions at which the pattern is placed can be called as the 'path' of the image.

The pattern, when at the final position of the path is made bright usually by multiple superpositions. This causes the final position to stand out bright and clear, while the previous positions remain comparatively dull and blurred, representing the 'history' of the pattern.

The number of steps used to produce the picture is important, in that a large number of steps produce a smooth image, but colors in the trail tend to add up to a saturation value. Fewer steps produce a more striated picture, but the colors tend to be closer to the original hues.

The pattern used need not remain constant while producing the scan image. It can change shape or color

smoothly with each step. However, since only the pattern of the final position is seen clearly, the patterns of the initial steps are lost. Here, scan animation can be used effectively.

To animate, the n th frame of the animation sequence is composed of the first n steps of the scan image. ie, the first frame shows only the first step; the second, the first two steps; and so on. This animation would show the pattern as it moves down the path. For each frame, the final step is brightened. Thus, as the pattern moves down the path the change in pattern can be observed.

Examples of SCAN images are shown in figures 1-4. Images in figures 1-2 are produced from a basic pattern of four squares which are subjected to rotation and movement towards the camera. Images in figures 3-4 are produced by similar manipulation of titles.

It seems in these images, that they capture fluidity of movement; and retain and display information of past positions of the pattern.

General Experiments

Experiments were conducted to observe the effects that can be produced using the SCAN technique. In the images of figures 5-12 the basic pattern is a set of three concentric squares. The path is a straight line and is directed toward the camera. Figures 5-7 are formed with comparatively few (90) steps; figures 8-12 are made of more (180) steps each. It can be observed that superposition of different colors can produce unexpected colored bands. Also, larger number of steps produce a less striated image. Some of the pictures suggest that the method can be used to generate images of concentric tubes.

Using a smoothly changing pattern, figures 13-20 were produced. In figures 13-16, the cross section is changed from a square to a highly elongated rectangle. In figures 17-20, the variation is from a thin to a fat cross section formed from french curves.

To check the observeability of intricacy in the patterns, some patterns were contrived. Images produced using a changing pattern is shown in figures 21-24. Movie sequences 1, 2 and 3 show these patterns as they evolve. These movie sequences indicate that

animation can considerably enhance the visualization of the pattern.

Figures 25-29 are studies of using curved paths, to see if curved channels can be represented using the scan technique. Movie sequences 4 and 5 are animations of these images.

Applying SCAN for displaying cross-sectional data

One of techniques that has been developed to visualize fluid flow parameters is to display the values of the parameter of interest at successive cross-sections of the channel[3]. The values are color coded, and the animation obtained by displaying successive cross-sections is used to convey the dynamics of the change in parameter value. An example of the type of image produced by this technique is shown in figure 30. However, in this technique, the cross-sections are not displayed along with the channel. The SCAN method can be combined with this method to display the cross-sectional data in relationship to the channel.

A series of experiments were conducted to study the image that can be thus produced. In figures 31-33 a test cross-sectional data pattern is superimposed to generate the images. The figures show the pattern along three different channel shapes. Animation of these images is given in movie sequences 6, 7 and 8.

In the images generated above, in the front cross-section, striations can be observed, caused by superimposition of patterns of the previous steps. To eliminate this artifact, the area corresponding to the

front cross-section can be masked out while recording the back sections, so that the area remains clear. When the final cross-section is superimposed, it is free of clutter. The same images as in figures 31-33 generated with the aid of such a mask are shown in figures 34-36. The patterns can be observed to be free of that clutter. Movie sequences 9, 10 and 11 animate these images.

However, in the above technique, there is a visual discontinuity between the pattern in the final step and the ones behind it. The blue pattern in the final step can be seen disjoint from the patterns of the previous steps. To preserve visual continuity, the mask can be selectively applied to the inner pattern alone (instead of the entire cross-section). Resulting images are shown in figures 37-39. A close examination of these will show the pattern from the previous steps coming right up to the front step, and yet the front pattern is uncluttered. Animation of the figures 37-39 is shown in movie sequences 12, 13 and 14.

This final technique appears to be the most suitable of the methods investigated for representing the cross-sectional data. Figures 40-45 show some more elaborate cross-sections represented using this technique. These are animated in movie sequences 15 through 20.

Conclusion

The technique that has been evolved can be used to represent data at successive cross sections of a channel. It provides a three dimensional perspective which is useful in spatially associating the data with the channel. The trail of past history of the data also aids in fixing this association. Intricacy of the patterns that can be observed is dependent only upon the resolution of the image. Animation of the image can improve visualization of the spatial behavior of the parameters.

The number of steps utilized is significant in that a large number of steps cause the trail (or smear) to saturate in color. About 100 to 200 steps are optimal. The brightening of the final step is necessary to enable the pattern being displayed to be clear and observeable. A superimposition of 10 to 15 instances of the final step is satisfactory.

Topics for future study

While displaying the cross-sectional data, sometimes the movement of the fluid along the plane of the section is also animated. This movement can also be represented in the technique developed here.

References

- [1] Parke, F. I. Adapataion of Scan and Slit_Scan Techniques to computer animation. SIGGRAPH, 1980
- [2] Sims, L. G. Animation, Scan and Slit Scan Photography. Proc. 25th Intl. Tech. Comm. Conf., Dallas 1978
- [3] Anderson et al. , Influence of Pressure Driven Secondary Flows on the behavior of Turbofan Forced Mixers. Sixteenth Joint Propulsion Conference, Hartford, Connecticut, Jun 30 - Jul 2, 1980.

Figures 1 to 45 are to be attached here Movie sequences 1 to 20 are also to be attached (This document is to be updated by replacing this page by copies of the photographs which form the pictures; and by including the animated movie sequences)